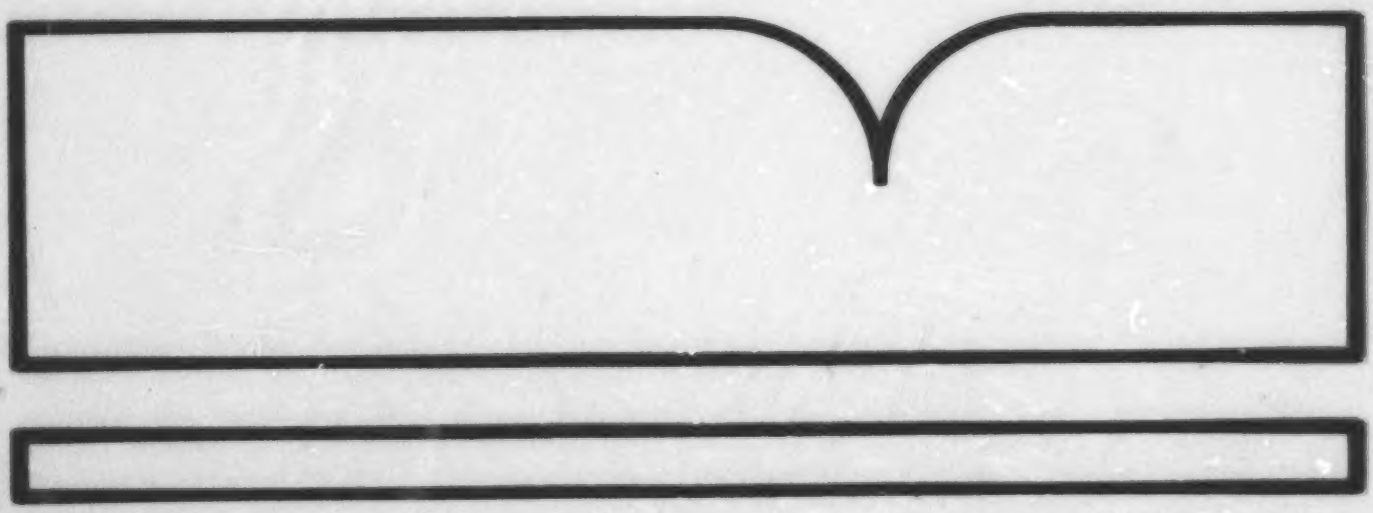
PB84-223528

Reverse Osmosis Treatment to Control Inorganic and Volatile Organic Contamination

(U.S.) Municipal Environmental Research Lab.
Cincinnati, OH

Jul 84



U.S. Department of Commerce
National Technical Information Service
NTIS

PB84-223528

EPA-600/D-84-198
July 1984

REVERSE OSMOSIS TREATMENT TO CONTROL INORGANIC AND VOLATILE ORGANIC CONTAMINATION

by

Thomas J. Sorg and O. Thomas Love, Jr.

Drinking Water Research Division
Municipal Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH 45268

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA *(Please read Instructions on the reverse before completing)*		
1. REPORT NO. EPA-600/D-84-198	2.	3. RECIPIENT'S ACCESSION NO. PB84-223528
4. TITLE AND SUBTITLE Reverse Osmosis Treatment to Control Inorganic and Volatile Organic Contaminantion.		5. REPORT DATE July 1984 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Thomas J. Sorg O. Thomas Love, Jr.		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS DWRD, MERL, OEET, ORD U.S. EPA Cincinnati, Ohio 45268		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS DWRD, MERL, OEET, ORD U.S. EPA Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE EPA/600/14
15. SUPPLEMENTARY NOTES Thomas J. Sorg 513/684-7370 O. Thomas Love, Jr. 513/684-7281		

16. ABSTRACT

Because of the versatility of reverse osmosis for removing a wide range of contaminants, U.S. EPA (Drinking Water Research Division) has been conducting laboratory and field studies to determine its effectiveness on specific inorganic and organic contaminants of concern to the water supply industry.

Laboratory and field studies for the removal of specific inorganic contaminants have shown that most of the contaminants listed in the EPA drinking water regulations are highly rejected(greater than 90%) while a few contaminants, such as fluoride, nitrate, and arsenic III, are only moderately rejected. Also, tests with different membranes showed only minor differences in removals.

Laboratory studies using cellulose and nylon amide membranes have shown less than 25% rejection of volatile organic compounds. A thin film composite membrane, on the other hand, looked very encouraging in short duration(less than 4 hours) tests for removing VOCs. However, when the thin film composite membrane was exposed to contaminated ground water for a longer term, certain VOCs, primarily unsaturated and aeromatic compounds, permeated the membranes within 12 to 16 hours. Thus, the future for RO in controlling VOCs is uncertain.

17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified 20. SECURITY CLASS *(This page)* Unclassified	21. NO. OF PAGES 23 22. PRICE

EPA Form 2220-1 (9-73)

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

REVERSE OSMOSIS TREATMENT TO CONTROL INORGANIC AND VOLATILE ORGANIC CONTAMINATION

by

Thomas J. Sorg and O. Thomas Love, Jr.

Drinking Water Research Division
Municipal Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency Cincinnati, OH 45268

INTRODUCTION

The principal application of reverse osmosis (RO) for producing drinking water in the U.S. has been for the treatment of ground waters having high total dissolved solids. This application illustrates the somewhat unique ability of RO to effectively remove a wide range of substances, such as sodium, chloride, hardness (calcium, magnesium) and sulfate that are commonly found in ground waters. Because of the high cost, its major disadvantage, however, the technology has experienced only limited usage; its principal market being in Florida and a few midwestern states having extensive brackish ground waters.

The ever expanding complexity of ground water problems suggest that RO may have a significant role in the future for producing drinking water. Thus, several years ago the Drinking Water Research Division (DWRD), USEPA developed an interest in evaluating RO for treating waters containing one or more of the inorganic contaminants listed in the National Interim Primary Drinking Water Regulations (NIPDWR) (1). More recently, this interest has expanded to the treatment for organic contaminant removal.

This paper is divided into two parts -- inorganics and organics. Part I, INORGANICS, reports on the results of several EPA supported studies on the effectiveness of RO to remove a variety of inorganic contaminants. Part II, VOLATILE ORGANICS, is concerned with the efficiency of reverse osmosis to remove volatile organic compounds from drinking water based upon DWRD inhouse studies.

Part I - INORGANICS

Reverse osmosis has been applied for many years for the treatment of sea waters and brackish waters. Consequently, information is readily available on the rejection capability of RO for the common inorganic substances, such as sodium, chloride, sulfate, hardness (calcium and magnesium) and total dissolved solids (TDS). A properly designed and operated system can achieve 95% removal of total dissolved solids. Rejections of specific contaminants varies with the rule of thumb being the higher the ionic charge and the larger the ion, the greater the removal. Percent removals for the common inorganics are shown in Table 1. These results are an average of removals achieved by four full scale RO plants operated in Sarasota County, Florida (2). The highest rejection, 96-97% was achieved for the divalent ions, SO_4^{-2}, Ca^{+2}, and Mg^{+2}. Slightly lower removals

are reported for the monovalent ions, chloride (86%) and sodium (80%). These results are in general agreement with manufacturer's literature with the possible exception of sodium and chloride that is commonly reported in the 88-92% range.

To develop data on the removal of the inorganics listed in the NIPDWR, the DWRD funded a cooperative agreement with the Charlotte Harbor Water Association (CHWA), Harbor Heights, Florida to conduct pilot plant studies. Initially, the study utilized two 45,000 gallons per day (gpd) capacity pilot RO systems: one unit was a low pressure system (~ 200 psi) and the other a higher pressure system (~ 400 psi).

A detailed description of these systems and results of the initial tests have been reported by Huxstep (3). More recent work has been conducted with a small, single module test system that was assembled and operated in a manner similar to the ASTM standard test method for Operating Characteristics of Reverse Osmosis Devices (4). The purpose of using a smaller, single module unit was to provide more flexibility in studying a number of new RO membranes.

The initial CHWA tests, using the two 45,000 gpd pilot systems, were conducted on CHWA ground water spiked with the contaminants most frequently found in ground waters, fluoride, nitrate and arsenic (III and V). Data were also collected on radium, the only naturally occurring contaminant found in the CHWA source water. A summary of these test results is given in Table 2. Highest removals achieved with the high pressure system were on arsenic V (98%) and radium (97%) followed by fluoride, nitrate and arsenic III. The low pressure membrane system results were about half of the high pressure system removals suggesting that only under unusual circumstances would this type of system be useful. The results also showed that for arsenic V, fluoride and nitrate removals were independent of the feed water concentration in the range tested (Figures 1-3). The most unusual result was with arsenic III that showed an extremely wide range of removals from a low of about 25% to as high as 97% (Figure 4). The reason suggested for the wide range is that the arsenic III specie ($HAsO_2$) can be easily oxidized to As V that is highly rejected.

Because of several operational problems and new developments in RO membrane technology, the Association changed its research approach to the use of a small, single module RO test system that provided more flexibility (Figure 5) in conducting tests with different membranes. Using this system, tests have been conducted on four different RO membranes. Also, the list of contaminants studied was expanded to include arsenic (III and V), cadmium, chromium (III and VI), fluoride, lead, nitrate, mercury (inorganic), selenium (IV and VI), radium and uranium. Because of occasional problems, operational and analytical, data are not available for every contaminant for each membrane.

Test procedures consisted of spiking the feed water (dechlorinated CHWA finished water) with one to three contaminants and running the system for a minimum of four hours. The only exception to this procedure was the use of natural ground waters from south Florida containing naturally occurring radium and uranium. During the test period, grab samples were collected of feed, product and reject waters after one hour of operation and at the end of the test. These samples were analyzed for the spiked contaminant(s) and for TDS, chloride, and hardness. System operating data, flows, pressures,

temperature and pH, were also recorded. Several concentrations of each contaminant were generally tested with the total number of samples for each contaminant ranging from a low of 5 to a high of 46 with the average being near 15.

Studies have been completed on three membranes, Toray (SC 3100), FilmTec (BW30-4021) and a Dow (RO-5K).[1] Tests with a fourth membrane, DuPont (0440-0-42) are partially completed. A general description of each membrane is given in Table 3.

The results of the tests completed to date are shown in Figures 6-10. The data show that high removals, greater than 96%, can be achieved for arsenic V, cadmium, chromium, lead, selenium and uranium. The only heavy metal that was not highly rejected was inorganic mercury (78%) which is contrary to manufacturers' estimates of greater than 90%. Because of the problems of sample preservation, the analytical test procedure, and the characteristic of mercury to adsorb to all types of materials, the results are questionable. Future work will continue to solve these problems.

As was found with the initial CHWA RO tests, lower removals in the 70-90% range were obtained with fluoride and nitrate (Figures 6 and 7). Also, lowest removals were again observed on arsenic III and the same wide range of removals were obtained with all tests (Figure 8).

Except for possibly nitrate and arsenic III, no major difference in removals have been observed between the membranes. Because of the conversion potential for arsenic III to arsenic V, actual differences in results between membranes is difficult to project.

Rejection data for fluoride, nitrate, arsenic and chromium obtained at several field locations are also plotted in Figures 6-10 (EPA/UH field system) for comparison with the pilot and laboratory test data. These data were obtained with a EPA-University of Houston mobile pilot plant facility equipped with a RO system with Dow Chemical Company and DuPont membranes (5). This system, operated by the University of Houston, has been used to conduct pilot plant tests for fluoride removal in Texas, nitrate and chromium removals in Arizona, and arsenic removal in New Mexico during the past several years. The results from these studies were in general agreement with both the CHWA pilot plant and laboratory test results. Also, no major differences in removals were observed between the Dow and DuPont membranes and between these specific membranes and those used by the CHWA in their laboratory tests.

INORGANIC SUMMARY

Laboratory, pilot plant and limited field tests show that most of the inorganic contaminants listed in the NIPDWR are highly rejected by RO systems regardless of the type of membranes utilized. Lowest removals are achieved for the monovalent ions, fluoride (90%) and nitrate (75%), and the nonionic As III ($HAsO_2$) specie (65%). Because arsenic III can be oxidized with chlorine or other oxidizing agents to arsenic V, a highly rejected ion, arsenic III can be easily handled

[1] Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

in an altered form. Additionally, removals of the primary regulated inorganics are comparable to the removals of the naturally occurring inorganics, such as, calcium, sulfate, chloride and sodium (Figure 11).

Reverse osmosis may appear more costly than most conventional treatment methods. However, because RO is capable of effectively removing a wide variety of inorganic contaminants, it may be more practical and cost effective for treating multiple contaminant problems that cannot be handled by any single conventional treatment method.

PART II - VOLATILE ORGANICS

Although reverse osmosis (RO) is not typically used to remove organic chemicals from drinking water, several studies (6-9) have shown that certain organic compounds are rejected by RO membranes. Most studies, however, have been concerned with nonvolatile and relatively high molecular weight pesticides. Little has been reported on the effects of RO on low molecular weight industrial solvents, particularly those being found in ground water (10). EPA-DWRD has conducted RO treatment studies on volatile organic compounds and Part II contains descriptions of the pilot scale RO units and some of the preliminary findings.

Experimental Protocol

EPA-DWRD has three reverse osmosis units (Table 4) for studying organics removal. The unit built by Holz RO/UF was designed to accommodate three different thin film composite (TFC) membranes, but thus far, only one (FilmTec) has been tested. Earlier, short term (<4 hrs) experimentation by Fronk[1] using distilled water spiked with volatile organic compounds (VOCs) showed little or no rejection of VOCs by a cellulose acetate membrane and in general, 25 percent or less rejection by a polyamide membrane. The TFC membrane, however, rejected greater than 99 percent of some of the VOCs, so an experiment was conducted using contaminated ground water to see if appreciable removals could be sustained over longer runs.

Five thousand gallons (19,000 L) of water from a contaminated well site in Indiana were trucked to the EPA-DWRD laboratory in Cincinnati, Ohio. Although the turbidity of this ground water was less than 1 NTU, the water was filtered (AMF, Cuno Aqua Pure® AP-100) before passage through the RO units. After one hour, influent, reject and permeate water samples were collected from each unit for analyses. The inorganic character of the various flow streams is shown in Table 5. The units, in general, removed 90 percent or more of the inorganic constituents.

The units were operated for 5 hours then shut off overnight. The following day, they were run for 8 hours and that consumed most of the available water. From the water remaining, 100 gallons (380L) were collected in a headspace-free stainless steel tank and recirculated through the TFC membrane for an additional total elapsed time of 307 hours. Because of the heat generated within the RO unit, a

---

1Carol Ann Fronk, EPA-DWRD Studies (paper in preparation).

water jacket was needed to keep the temperature of the recirculated water constant.

Organic Removal

The organic quality of water before and after RO treatment is shown in Table 6. The cellulose acetate membrane removed a high percentage of the total organic carbon (TOC) but not the individual volatile organic compounds. The polyamide membrane similarly removed a high percentage of the TOC but it also removed a high percentage of 1,1,1-trichloroethane, and to a lesser degree, trichloroethylene and benzene. This is consistent with the findings of others (11,12). The thin film composite membrane removed a high percentage of all the organics for the first hour then the removal efficiency steadily declined for certain compounds. This decline in efficiency is perhaps more easily seen in Figure 12 where the individual organic compound concentrations are summed and the percent VOCs remaining is plotted against the elapsed time over the course of the study. In less than 20 hours (total elapsed time) the net treatment result was that the thin film composite membrane behaved much as the polyamide membrane. Note, during the entire run the total dissolved solids removal, as measured by a Myron L® DS meter, remained at $\geq$ 99 percent, so the TFC membrane was intact, but apparently some of the organics were diffusing through. Also note, the effects of organic "permeation" are cumulative, so running an RO unit intermittently does not change the net results.

After about 300 hours of use, the TFC unit was flushed for one hour with 165 gallons (625 L) of tap water that had been passed through hydrogen exchange resin (Continental Water Systems). This was followed by 30 minutes flushing with distilled water [approximately 100 gal (380 L)]. When the unit was returned to service, two things were noted: one, the removal efficiency was not well restored (Figure 13, Part A) and two, the permeate and reject streams from the RO unit contained over 50 ug/L of 1,2-dichloroethane, a VOC not found in the contaminated ground water.

Subsequent investigation showed that 1,2-dichloroethane had desorbed from the hydrogen exchange resin at a concentration of almost 1,800 ug/L and sorbed on the TFC membrane during the flushing cycle. The RO unit was shut down and reflushed for 2 hours with distilled water [approximately 200 gal (760 L)]. The organic quality of the permeate during the flushing cycle is shown in Figures 14A and 14B. Even after 2 hours of flushing approximately 70 ug/L of total VOCs remained in the permeate (Figure 14B).

After the 2-hour distilled water flush, the unit was put back into service for an additional 13 hours (Figure 13, Part B). Although some improvement in removal effiency may have been experienced within the first hour or so after flushing, the improvement was short lived. The membrane was then flushed for 9 hours with distilled water. Even at the end of that flush cycle, 12 ug/L of trichloroethylene remained in the permeate (Figure 14B).

The contaminated ground water was drained from the recirculation tank and distilled water, spiked with several VOCs, was recirculated through the RO unit. The results of this test are given in Table 7. To summarize these findings, only two organic compounds (carbon tetrachloride and 1,1,1-trichloroethane) were consistently rejected

(> 98%) by this membrane. Of the remaining 9 compounds, 5 of them (trichloroethylene, tetrachloroethylene, chlorobenzene, ortho- and meta-dichlorobenzene) were "sorbed" on the membrane. These "sorption" losses were easily monitored in the recirculated system and ranged between 40 and 90 percent during this 21 hour experiment.

Discussion

Because earlier laboratory experiments using a thin film composite membrane were very encouraging for removing organics, it was speculated that if a utility already using RO (with a cellulose acetate or polyamide membrane) to control inorganics found their water to be contaminated with VOCs, the simplest solution might be to change to a TFC membrane to combat both inorganic and organic problems. Follow-up organic removal studies, however, were disappointing. Certain organic compounds (particularly trichloroethylene and benzene), permeated the TFC membrane within a few hours, making short term testing misleading. Also, many volatile organic compounds "sorb" on the membrane and desorption (with distilled water flushing) takes several hours. On the other hand, two saturated compounds, carbon tetrachloride and 1,1,1-trichloroethane, were rejected, so, RO used in conjunction with adsorption or aeration might be a practical consideration in some cases. Because different membranes are available (13), some other operating "combinations" may give better removal efficiencies for certain organics. Regardless, when RO is being evaluated for removing organic compounds, the tests should be conducted for at least 15 to 20 hours, rather than one to two hours duration. Also, other membrane cleaning techniques need to be examined.

Acknowledgement

Appreciation is expressed to Kenneth Kropp, Bradford Smith and Carol Ann Fronk for their assistance in conducting the organic removal experiments. Special thanks to Maura Lilly, Virginia Maphet, Patricia Pierson and Herb Braxton for their help.

REFERENCES

1. National Interim Primary Drinking Water Regulations. EPA-570/979-003, Ofc. of Wtr. Sply. Washington, DC (1976).

2. Sorg, T. J., Forbes, R. W. and Chambers, D. C. Removal of Radium-226 from Sarasota County, Florida Drinking Water by Reverse Osmosis. Jour. AWWA, 72:3:230 (Apr. 1980).

3. Huxstep, M. R. Inorganic Contaminant Removal from Drinking Water by Reverse Osmosis. EPA 600/2-81-115. Ofc. Res. Develop., Cincinnati, OH (Oct. 1981).

4. Standard Test Method of Operating Characteristics of Reverse Osmosis Devices, D4194-82. ASTM, Philadelphia, PA (1982).

5. Clifford, D. and Bilimoria, M. A Mobile Drinking Water Treatment Research Facility for Inorganic Contaminants Removal: Design, Construction, and Operation. EPA-600/2/84-018. Ofce. Res. Develop., Cincinnati, OH (Mar. 1984).

6. Smola, D.J. Removal of Toxic Pesticides by Reverse Osmosis Water Treatment. Master's Thesis, Massachusetts University, Department of Civil Engineering, Amherst, MA (Dec. 1968).

7. Hindin, E., Bennett, B.J. and Narayanan, S.S. Organic Compounds Removed by Reverse Osmosis. Water and Sewage Works, 116:466(1969)

8. Lonsdale, H. K., Milstead, C. E., Cross, B. P. and Graber, F. M. Study of Rejection of Various Solutes by Reverse Osmosis Membranes. R and D Report No. 447, Office of Saline Water, Washington, D. C. (July 1969).

9. Edwards, V.H. and Schubert P.F. Removal of 2,4-D and Other Persistent Organic Molecules from Water Supplies by Reverse Osmosis. Jour. AWWA, 66:10:610 (Oct.1974).

10. Federal Register, National Revised Primary Drinking Water Regulations, Volatile Synthetic Organic Chemicals in Drinking Water, 47:3:4350 (March 4, 1982).

11. McCarty, P. L. and Aieta, E. M., Chemical Indicators and Surrogate Parameters for Water Treatment. Proceedings, AWWA Annual Conference, Las Vegas, NV (June 1983).

12. Argo, D. G., The Lime/RO Process and Its Role in Water Reclamation for Southern California. Presented at the 56th Annual Water Pollution Control Federation Conference, Atlanta, GA (Oct. 1983).

13. Mattson, M.E. and Lew, M. Recent Advances in Reverse Osmosis and Electrodialysis Membrane Desalting Technology, DeSalination, 41:1:1 (Apr. 1982).

TABLE 1. REVERSE OSMOSIS SYSTEM REMOVALS*

Constituent	Average Percent Removal
TDS	95
Hardness	96
Calcium	96
Magnesium	96
Sodium	80
Chloride	86
Sulfate	97

*Average from four RO plants in Sarasota County, FL (2).

TABLE 2. SUMMARY OF CHWA TEST RESULTS USING 45,000 GPD PILOT REVERSE OSMOSIS SYSTEMS

Contaminant	Percent Removal	
	High Pressure RO System (~400 psi)	Low Pressure RO System (~200 psi)
*Arsenic III	25 - 97	12 - 35
*Arsenic V	95 - 98	77 - 81
*Fluoride	87 - 93	56 - 62
*Nitrate	76 - 80	6 - 24
Radium-226	97	62
Total Dissolved Solids	93 - 96	45 - 52

*Spiked

TABLE 3. GENERAL DESCRIPTION OF RO ELEMENTS USED IN INORGANIC CONTAMINANT REMOVAL TESTS

Information	Membrane Element - Manufacturer			
	Toray	FilmTec	Dow	DuPont
Manf. No.	SC 3100	BW30-4021	RO-5K	0440-0-42
Type	Spiral Wound	Spiral Wound	Hollow Fiber	Hollow Fiber
Material	Cellulose Acetate	Non-Cellulosic Thin Film Composite	Cellulose Triacetate	Polyamide
Max. Operating Pressure-psig	600	200	450	400
Max. Chlorine Conc. - mg/L	1	1	1	0
Recovery per Element - %	10	10	75	75
pH Range	4 - 7.5	4 - 10	4 - 7.5	4 - 11

TABLE 4. REVERSE OSMOSIS UNITS USED BY EPA-DWRD TO STUDY ORGANICS REMOVAL

Manufacturer	Membrane	Operating Pressure, psi (kPa)	Flow, L/min		
			Reject	Permeate	Total
Osmonics, Inc. Minnetoka, Mn	cellulose acetate spiral wound, 19 ft^2 (1.8 m^2) surface area	235 (1620)	4.7	0.4	5.1
Continental Water Systems, El Paso, TX	DuPont Permasep® B9, polyamide hollow fiber, 3000 ft^2 (276 m^2) surface area	150 (1035)	4.9	1.1	6.0
Holz RO/UF Fredericksburg, VA	Filmtec® FT-30, thin film composite, spiral wound, 25 ft^2 (1.9 m^2) surface area	200 (1380)	9.5	1.5	11.0

TABLE 5. INORGANIC QUALITY* OF GROUND WATER BEFORE AND AFTER TREATMENT BY REVERSE OSMOSIS

Parameter	Influent	Cellulose Acetate		Polyamide		Thin Film Composite	
		Permeate	Reject	Permeate	Reject	Permeate	Reject
Total Dissolved Solids	252	12	281	20	304	2	272
Chloride	20.2	2.36	19.0	2.08	21.7	< 0.1	17.5
Sulfate	28	< 15.0	31.0	< 15.0	36.0	< 15.0	33.0
Sodium	10.2	1.5	11.6	3.2	12.8	1.6	12.0
Barium	< 0.2	—	—	—	—	0.3	—
Arsenic	< 0.005	—	—	—	—	—	—
Selenium	< 0.005	—	—	—	—	—	—
Fluoride	< 0.1	—	0.2	—	0.1	—	—
Hardness, as $CaCO_3$	258	11	282	15	328	1	295
Alkalinity, as $CaCO_3$	173	10	184	18	191	4	189
Conductance, umhos/cm	448	24	454	42	652	5	464
Chromium	< 0.005	—	—	—	—	—	—
Silver	< 0.03	—	—	—	—	—	—
Copper	< 0.02	—	—	—	—	—	—
Manganese	0.12	< 0.03	0.14	< 0.03	0.16	< 0.03	0.14
Lead	< 0.005	—	—	—	—	—	—
Iron	< 0.1	—	—	0.13	—	—	0.10
Cadmium	< 0.002	—	—	—	—	—	—
Zinc	< 0.02	—	—	—	—	—	—
Mercury	< 0.0005	—	—	—	—	—	—
Turbidity, NTU	0.46	0.06	0.38	0.07	0.24	0.07	0.46
Color, units	4	3	3	4	4	2	5
pH, units	7.70	6.10	7.60	6.60	7.70	5.50	7.80

* all units mg/L except as noted.
-- indicates below detection.

TABLE 6. ORGANIC QUALITY OF GROUND WATER BEFORE AND AFTER TREATMENT BY REVERSE OSMOSIS

$$\text{Percent Removal} = \frac{\text{Influent-Permeate}}{\text{Influent}} \times 100$$

Organic Parameter	Average Influent Conc.	Cellulose Acetate			Polyamide			Thin Film Composite		
		Elapsed Time			Elapsed Time			Elapsed Time		
		1 hr.	5 hr.	13 hr.	1 hr.	5 hr.	13 hr.	1 hr.	5 hr.	13 hr.
Total Organic Carbon	2.0 mg/L	85	90	90	85	68	91	86	81	89
Total Organic Halogen	89.4 ug/L	<10	53	34	38	64	64	80	82	88
Cis-1,2-Dichloroethylene	57.9 ug/L	<10	<10	<10	10	10	19	83	45	25
1,1,1-Trichloroethane	6.1 ug/L	<10	<10	<10	88	89	92	>99	>99	>99
Trichloroethylene	110.5 ug/L	<10	<10	<10	18	24	32	99	97	78
Benzene	25.6 ug/L	<10	<10	<10	18	16	18	82	37	15

TABLE 7. REMOVAL OF VOLATILE ORGANIC COMPOUNDS* BY A THIN FILM COMPOSITE RO MEMBRANE

Organic Compound	Average Influent conc., ug/L	Percent Removal				
		1 hr.	3 hr.	6 hr.	9 hr.	21 hr.
Benzene	39	52	20	18	18	19
Carbon tetrachloride	109	98	98	98	98	98
Chlorobenzene	23	98	96	85	72	50
1,2-Dibromomethane (EDB)	8	88	34	39	15	15
m-Dichlorobenzene	26	95	91	88	85	66
o-Dichlorobenzene	36	93	88	85	83	70
1,2-Dichloroethane	50	49	34	29	29	37
cis-1,2-Dichloroethylene	65	47	6	24	12	20
Tetrachloroethylene (PCE	95	99	98	97	84	68
1,1,1-Trichloroethane	90	98	98	98	98	98
Trichloroethylene (TCE)	97	89	66	35	26	30

*Spiked in distilled water.

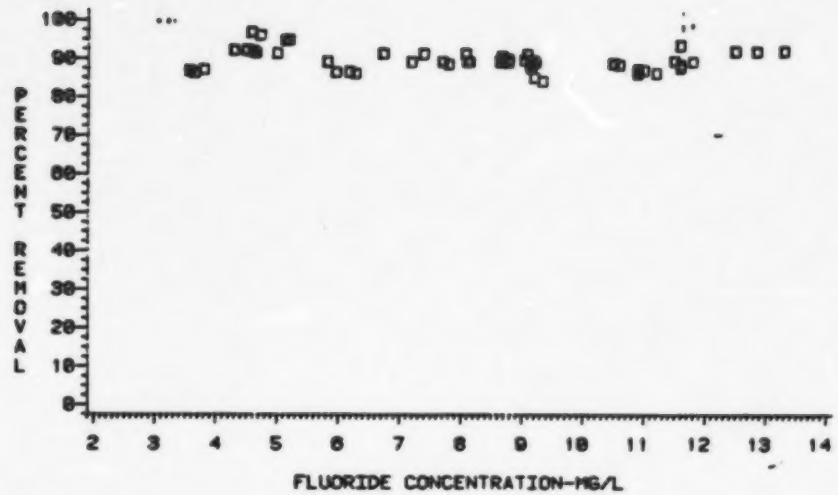


Figure 1. Fluoride removal with CHWA 45,000 GPD high pressure RO system.

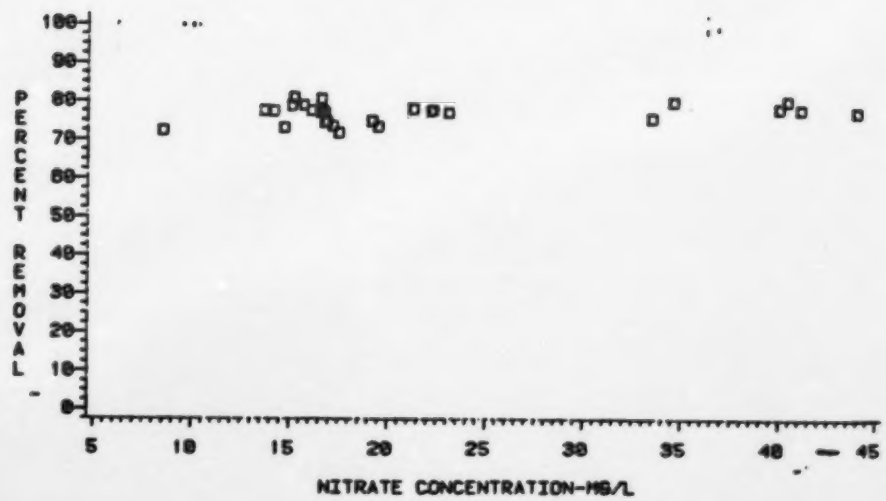


Figure 2. Nitrate-N removal with CHWA 45,000 GPD high pressure RO system.

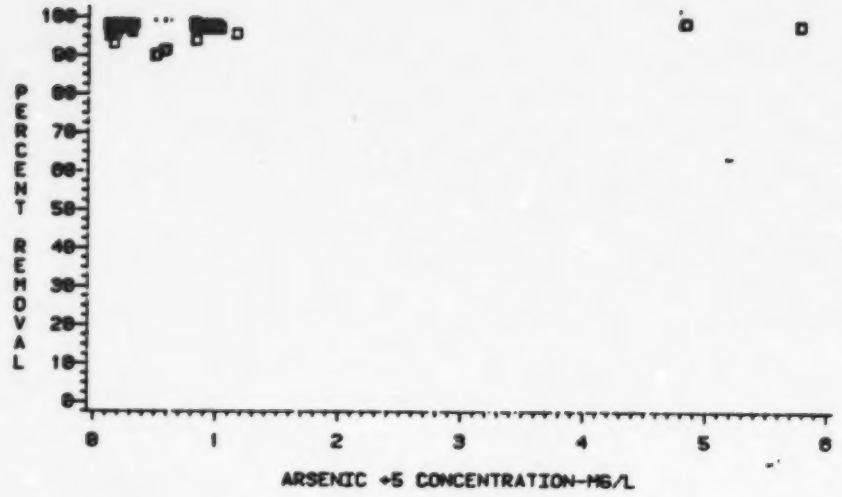


Figure 3. Arsenic V removal with CHWA 45,000 GPD high pressure RO system.

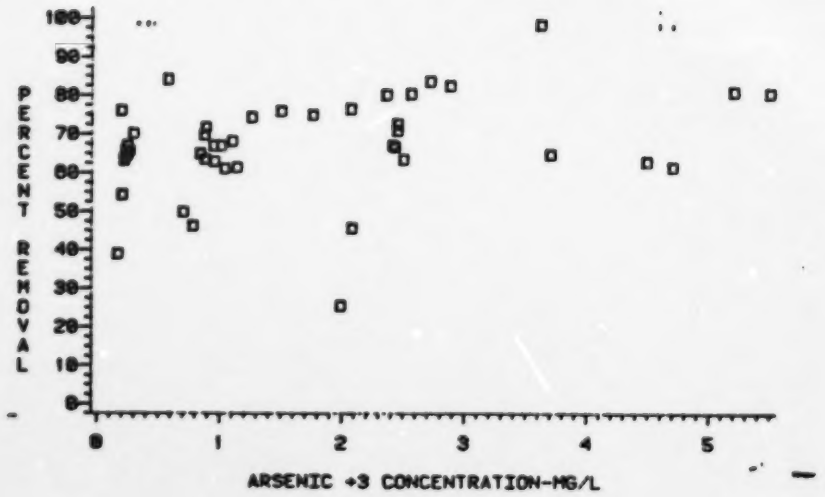


Figure 4. Arsenic III removal with CHWA 45,000 GPD high pressure RO system.

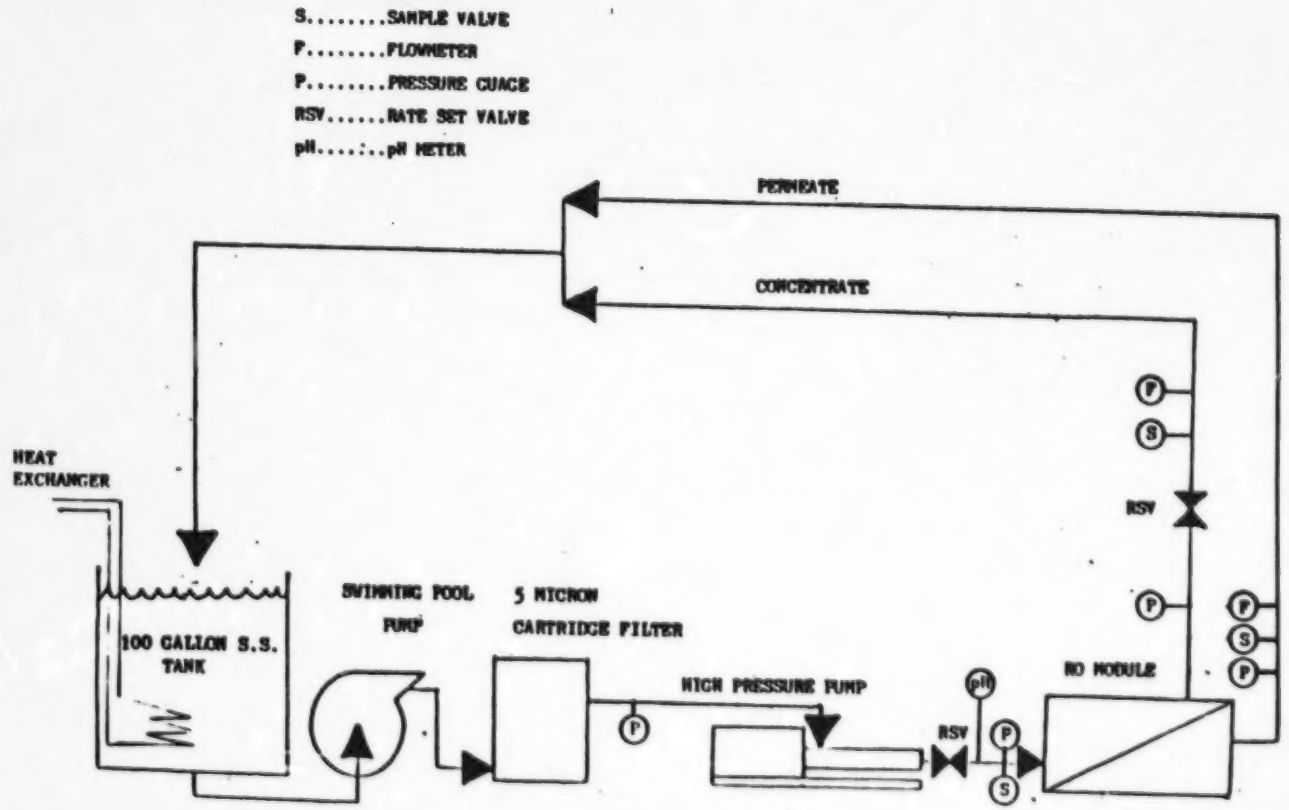


Figure 5 Flow diagram of CHWA 5000 GPD reverse osmosis research unit.

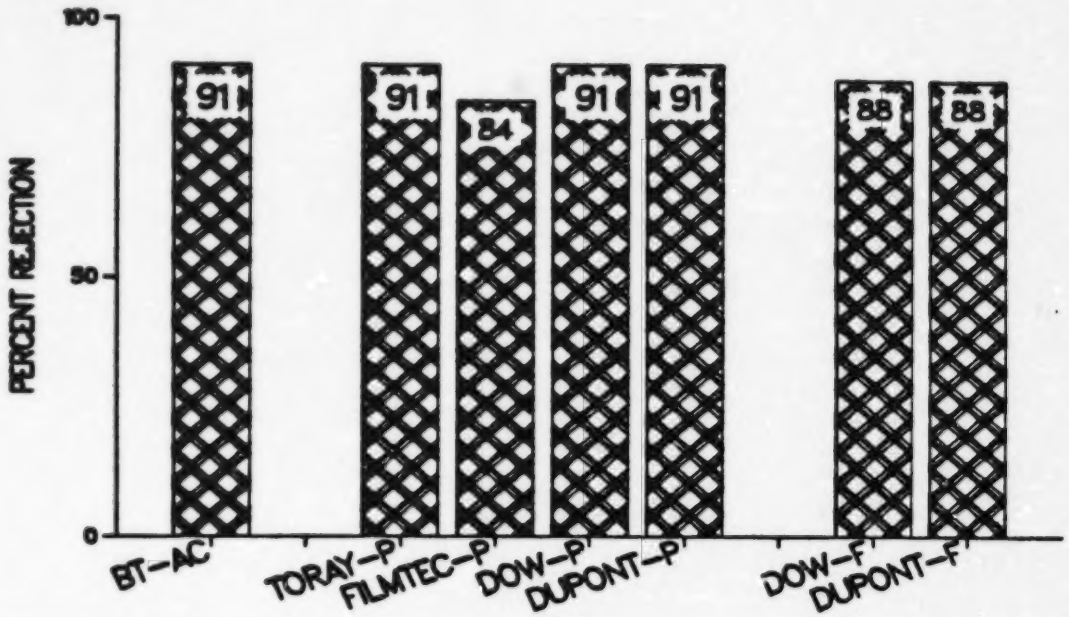


Figure 6. Fluoride removal with various RO systems and membranes.

BT-AC - CHWA 45,000 GPD system
P - CHWA 5,000 GPD pilot system
F - EPA/UH field system

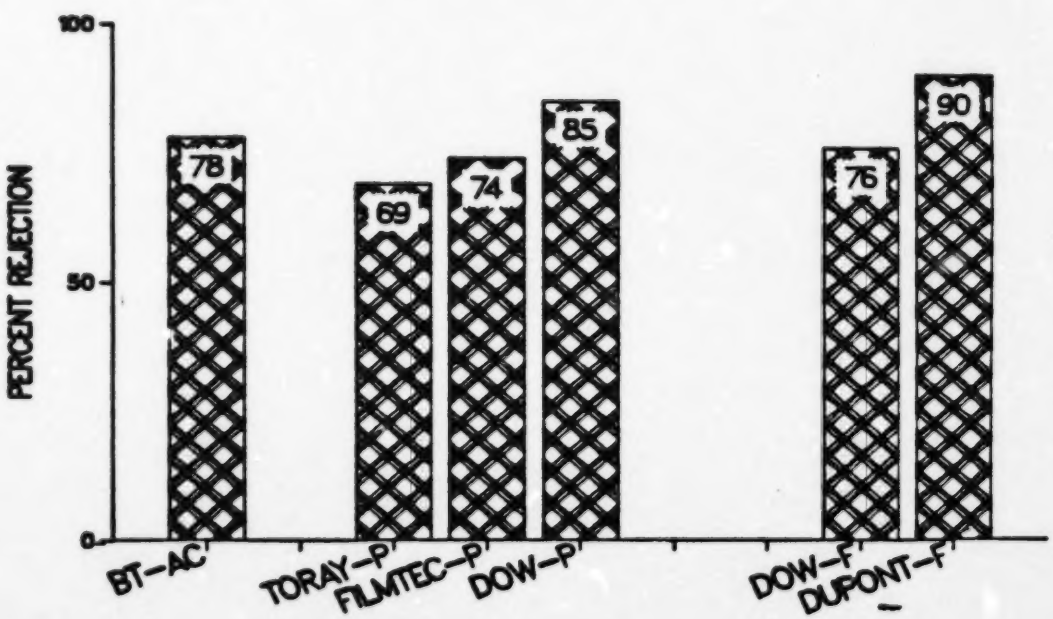


Figure 7. Nitrate removal with various RO systems and membranes.

BT-AC - CHWA 45,000 GPD system
P - CHWA 5,000 GPD pilot system
F - EPA/UH field system

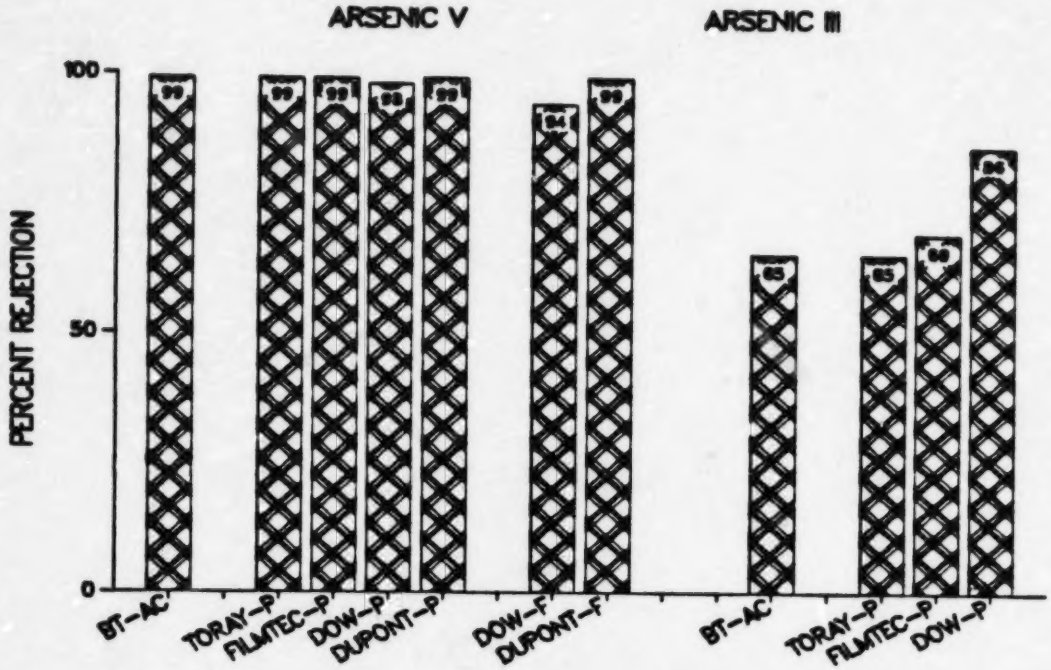


Figure 8. Arsenic removal with various RO systems and membranes.

BT-AC - CHWA 45,000 GPD system
P - CHWA 5,000GPD pilot system
F - EPA/UH field system

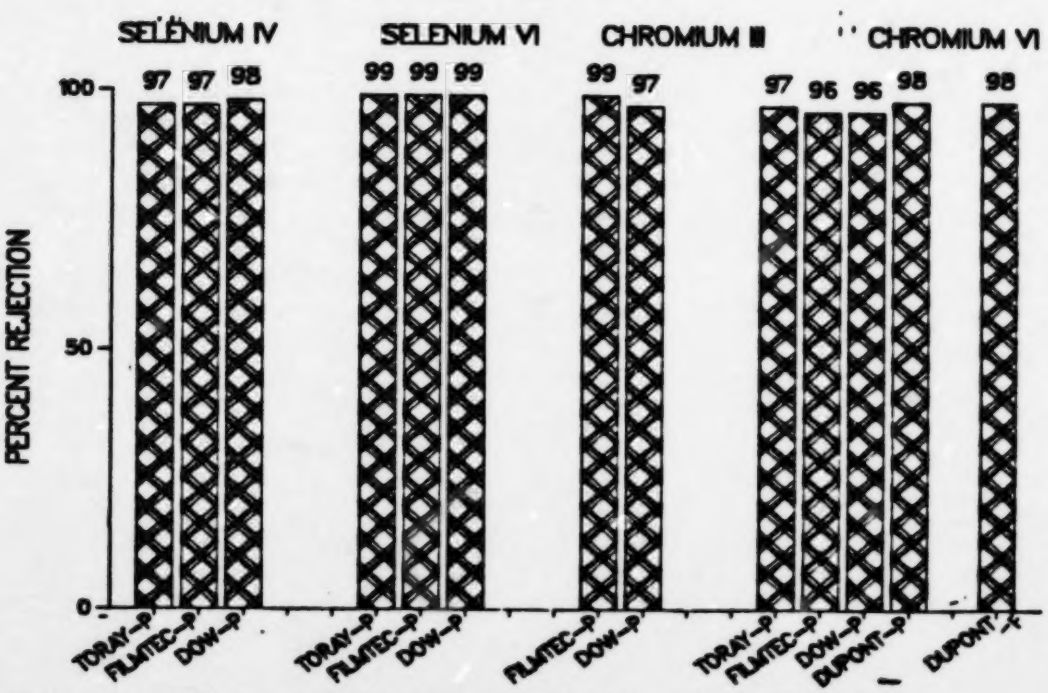


Figure 9. Selenium and chromium removal with various RO systems and membranes.

P - CHWA 5,000 GPD pilot system
F - EPA/UH field system

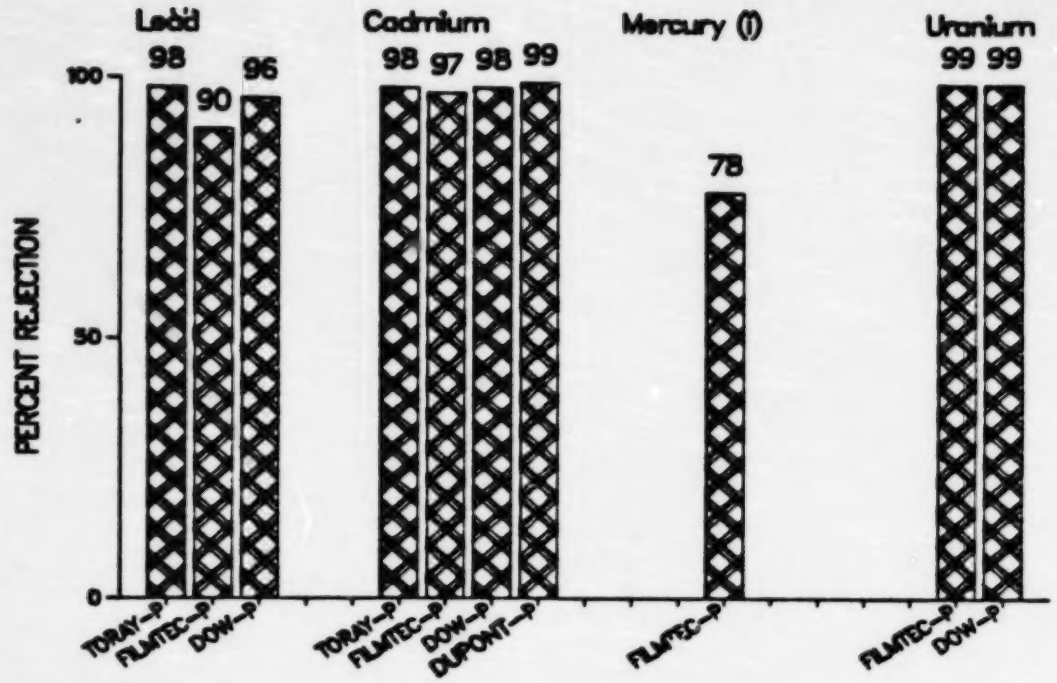


Figure 10. Lead, cadmium, mercury and uranium removal with the CHWA 5,000 GPD RO system.

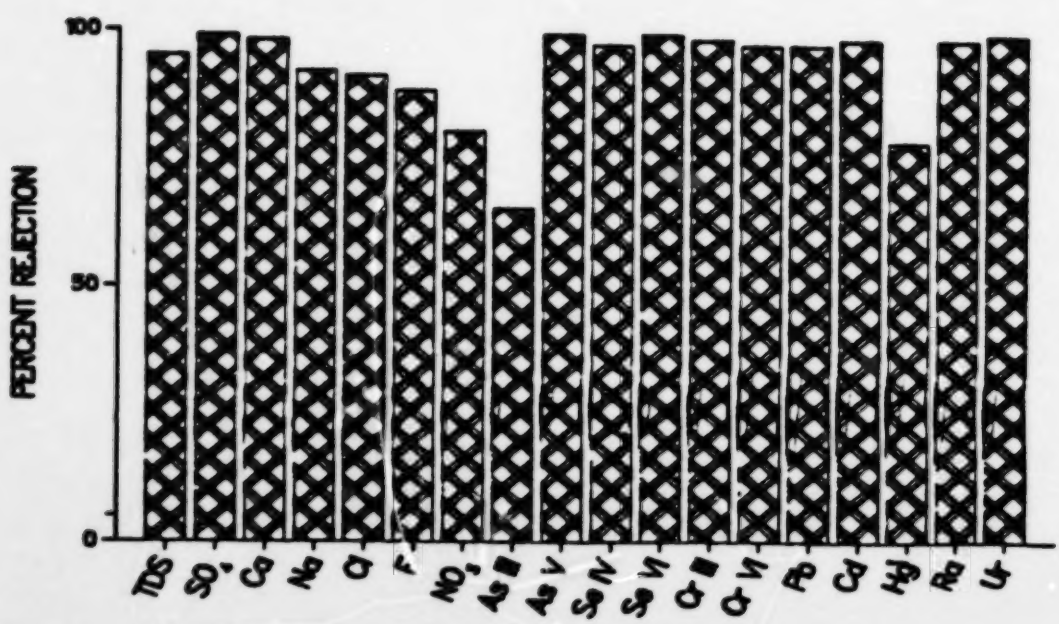


Figure 11. Summary of specific contaminant removal by RO.

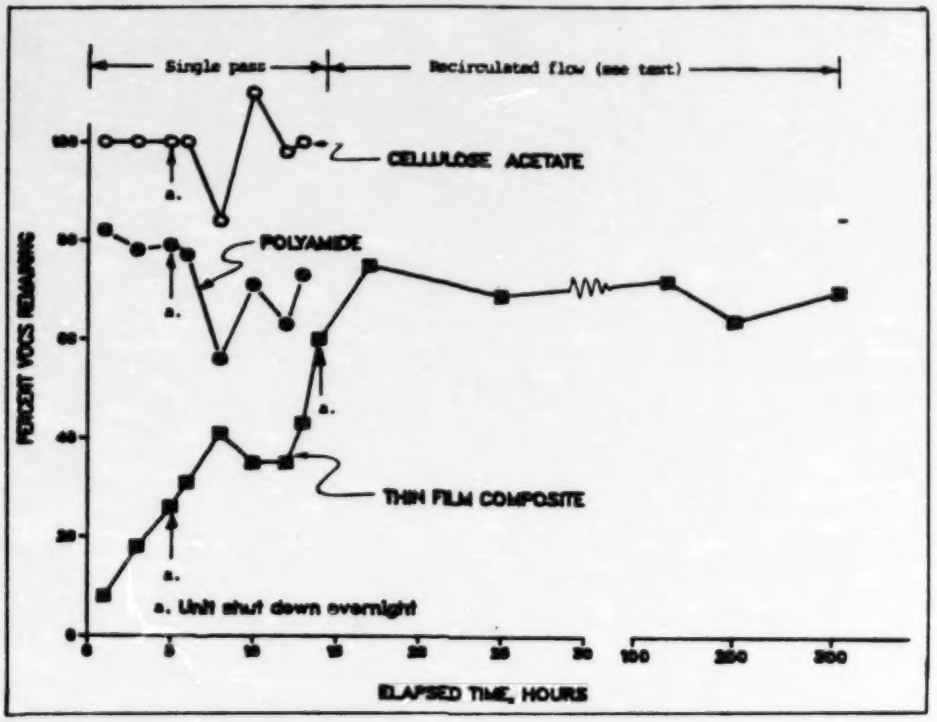


Figure 12. Removal of volatile organic compounds from ground water by reverse osmosis.

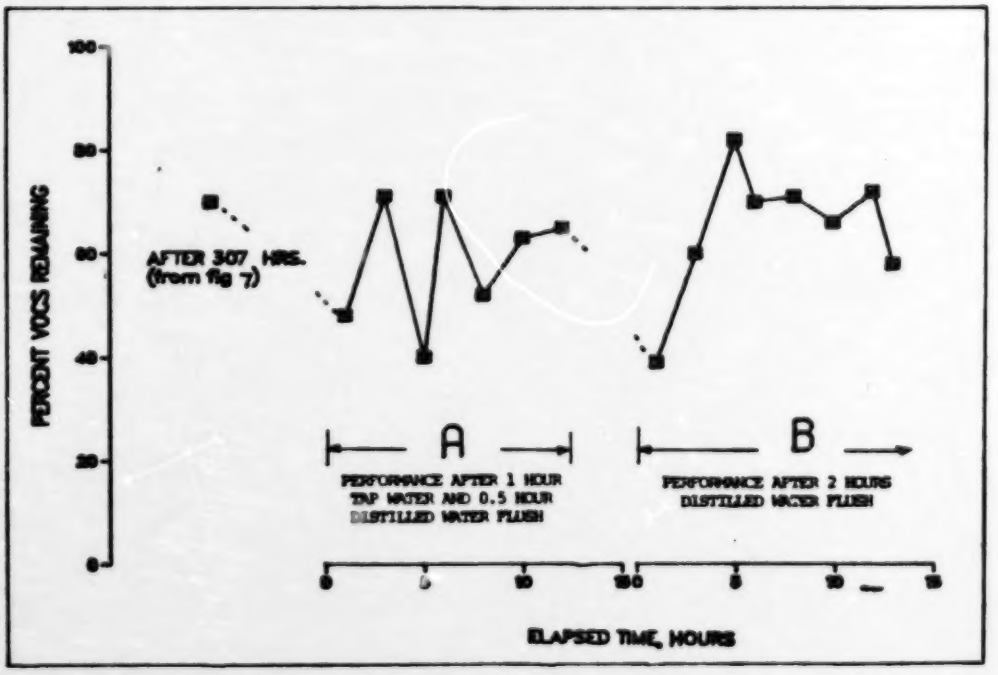
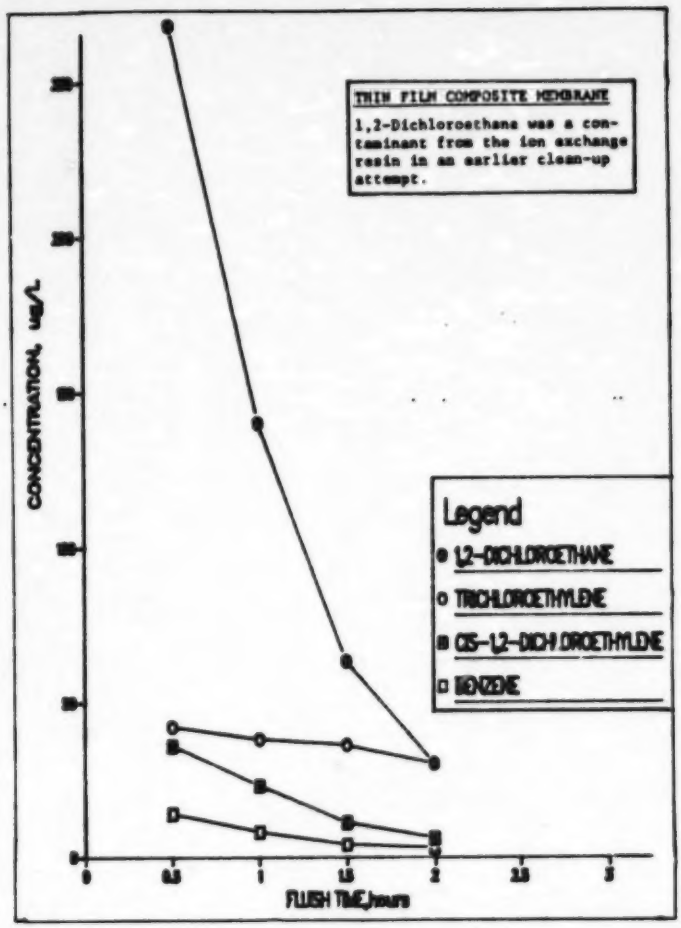
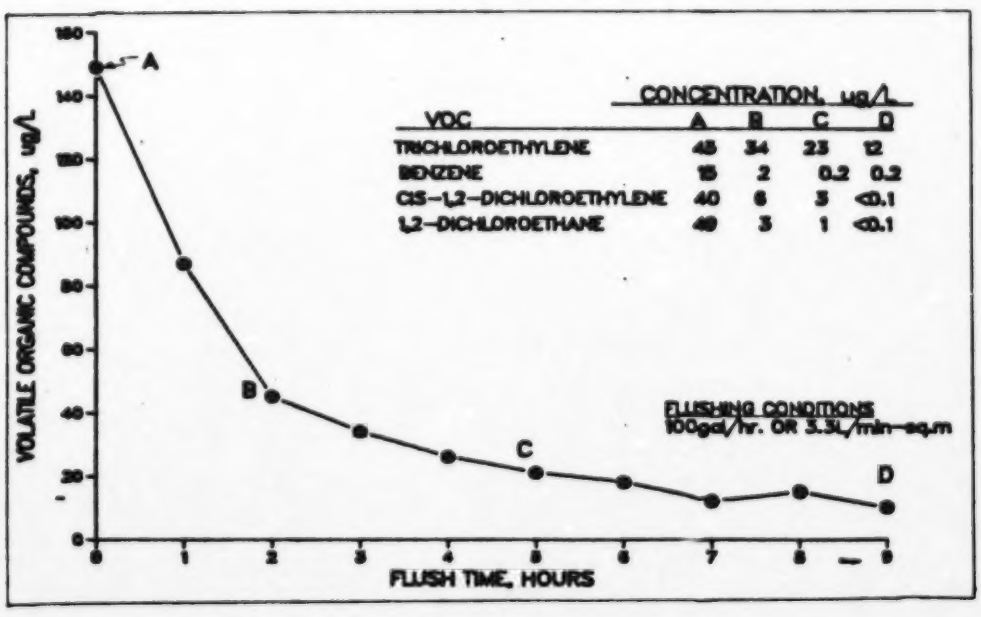


Figure 13. Effects of flushing on VOC removal by thin film composite reverse osmosis system.

A.



B.



VOC	CONCENTRATION, ug/L A	B	C	D
TRICHLOROETHYLENE	45	34	23	12
BENZENE	15	2	0.2	0.2
CIS-1,2-DICHLOROETHYLENE	40	6	3	<0.1
1,2-DICHLOROETHANE	49	3	1	<0.1

Figure 14. VOC concentration in permeate from thin film composite membrane verse time of flushing with distilled water.